VISIBLE AND CHEMICAL FLAME LENGTHS OF ACETYLENE/AIR JET DIFFUSION

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Introduction

The lengths of turbulent diffusion flames have been widely studied experimentally and theoretically. Flame lengths are typically defined in terms of the mean temperature, chemical composition or luminosity along the axis. For many flames, the interchangeable use of the different definitions, that frequently occurs in the literature, may cause qualitative and quantitative discrepancies amongst data and confusion regarding the importance of different physical processes. There are several existing models for flame length correlations [1-6]. The significant assumption in most of the flame length correlation is that the visible flame length is proportional to local chemical state. One complication that these existing models do not address is that of soot. If a large fraction of the fuel mass is converted to soot, then the visible flame length would be determined by radiation emitted by the hot soot particles. The radiation transferred from the hot soot particles to the surroundings lowers that temperature of the soot and flame gas mixtures making the flame non-luminous. Gore et al. [7] have shown that the peak temperature along the centerline occurs much closer to the injector exit in strongly radiating flames than in weakly radiating flames. Therefore, the definition of flame length based on this visible luminosity is inconsistent. Based on the above, the objective of the present work was to obtain flame lengths based on measurements of axial gas species concentrations.

Experimental Methods

The visible and chemical flame heights for acetylene/air diffusion flames ranging from 1 to 40 kW issuing from three burner diameters were measured during this study. Visible flame length (H_f) was measured by averaging 40 video frames obtained using a CCD camera, with a shutter time of 1 ms. A neutral density filter was placed in front of the camera to avoid pixel blazing. The axial concentrations of the major gas species within the flames were measured using a water cooled stainless steel probe and gas chromatography. The chemical flame length ($H_{f,c}$) was taken as the axial location at which X_{fuel} drops to 0.0005 [1], which is the lower detection limit of the instrument.

Results and discussion

The lower flow rate acetylene/air diffusion flames stabilized on the burner exit, while the higher flow rate flames were lifted from the burner. The visible flame length increased monotonically with increasing heat release rate. At low heat release rates, significant amounts of dark soot leave the cooler orange tip of the flames. As the heat release rate increases, large amounts of soot continue to exit the tip of the flame but the center of the flame becomes very bright, indicating high temperatures. When the flames are lifted, the whole length appears bright white and virtually no dark soot is visible above the flame. Similar behavior is observed for all three burner diameters, with the transitions described above occur at relatively low heat release rates for the lower diameter burners. The variation in visible flame length discussed above for a gaseous flame suggests that soot formation and radiation phenomena affect the visible flame length of both types of flames. The chemical flame length remains almost constant when compared to the visible flame length. No discontinuity occurs in the visible or the chemical flame length across the transition from attached to lifted flames. Differences in visible and chemical flame lengths are most pronounced at high heat release rates on the 2.1 mm diameter burner where $H_{f,v}$ is more than one and a half times $H_{f,c}$. For lower flow rates on the 4.8 mm burner, $H_{f,c}$ is longer than $H_{f,v}$ which may be attributed to the use of the neutral density filter. In all cases, the visible flame length data in this study were shorter than those predicted by the correlations in the literature [2,4,6]. This can be attributed to the use of a neutral density filter over the video camera lens which blocks out the less luminous flame tip.

Becker and Liang [2] obtained their correlations as curve fits for methane, ethane, and propane visible flame lengths. Acetylene flame length data obtained by Becker and Liang [2] themselves show that momentum dominated flames follow their stabilized flame correlation. As the flames become more buoyant, they become shorter than those predicted by the correlation. The visible flame length data from this study are similar to those of Ref [2], and both are overestimated by the correlations. The visible and chemical flame lengths from the present study are plotted according to the correlation by Delichatsios [4] in fig. 1. The acetylene flames tested in the present study are all in the "purely momentum turbulent" regime according to the classification given by Delichatsios [4]. The data fall into regions of both momentum and buoyancy control, as shown in fig. 1. Delichatsios predicts a smooth transition between the two regimes, but $H_{f,v}$ is qualitatively similar to the buoyancy dominated prediction at all fire Froude numbers. The chemical composition based flame length is not similar to the correlation in the buoyancy regime but qualitatively similar to the trend in the momentum controlled

regime. However, there is a factor of two difference between the momentum dominated limiting values measured in the present work and those predicted by Delichatsios [4].

The most recent dimensional analysis of turbulent jet flames is given by Blake and McDonald [5,6] and the resulting correlations are plotted in fig. 2 with the present data. The data for visible flame length are in qualitative agreement with the buoyancy dominated correlation. The correlation also classifies all of the present flames as buoyancy dominated. However, the present chemical composition based flame length data show that most of the present flame lengths are almost constant or increase very slowly with increases in Froude number, even in this buoyancy regime. The correlations were developed with the fundamentals of turbulent mixing and reaction but were calibrated using visible flame length data. However, for the present acetylene flames the correlations do not even qualitatively predict the chemical composition based flame length. The differences between $H_{f,v}$ and $H_{f,c}$ are attributed to the sooting characteristics of acetylene. Soot causes the bright yellow color in the flame, reduces the amount of fuel that reacts to form gaseous products, and cools the flame radiatively, which reduces the length for which the soot is visible. Transport of high temperature and high concentration soot further along the axis causes the visible flame length to increase. Visible flame length correlations for luminous flames should include soot chemistry and radiative cooling considerations.

Conclusions

This investigation shows that visible flame length and chemical flame length are not the same and do not follow the same scaling with flowrate in acetylene flames. The use of general non-dimensional flame correlations to predict the chemical behavior of highly sooting flames could be hampered without this understanding of the difference between chemical length and visible length. Flame length would be further clarified by more investigation into soot transport and chemistry.

Acknowledgments

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References

1. Hawthorne, W. R., Weddell, D. S., and Hottel, H. C., *Third Symposium on combustion and Flame and Explosion Phenomena*, Williams and Wilkins, Baltimore, 1949, pp. 266-288.
2. Becker, H. A. and Liang, D., *Combust. Flame* 32:115-123 (1978).
3. Becker, H. A. and Yamazaki, S., *Combust. Flame*, 33: 123-150 (1978).
4. Delichatsios, M. A., *Combust. Flame*, 92:349-364 (1993).
5. Blake, T. R. and McDonald, M., *Combust. Flame* 94: 426-432 (1993).
6. Blake, T. R. and McDonald, M., *Combust. Flame* 101: 175-184 (1995).
7. Gore, J. P., Ip, U.-S., and Sivathanu, Y. R., *Journal of Heat Transfer*, 114:487-493 (1992).

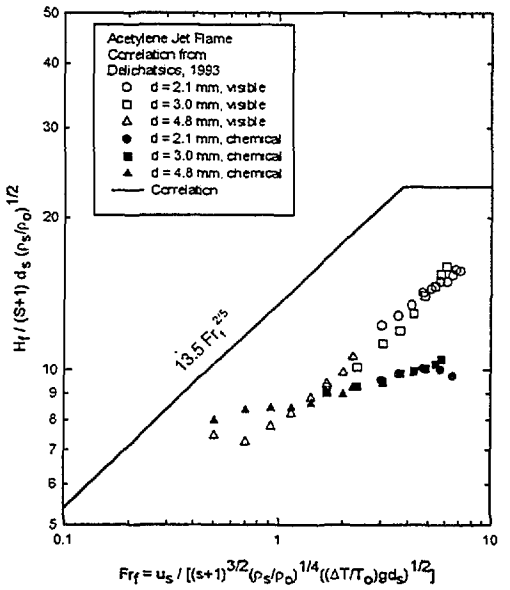

Figure 1. Jet Flame Correlation from Delichatsios [4].

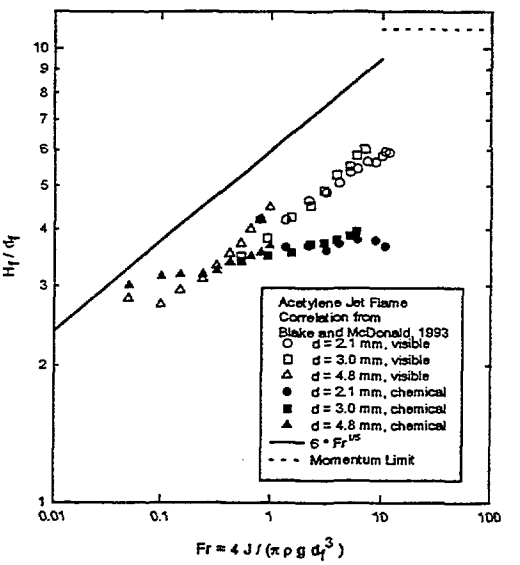

Figure 2. Jet Flame Correlation from Blake and McDonald [6].